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ORIGINAL RESEARCH

Agro-environmental assessment of composting plants in Southwestern of Morocco (Souss-Massa Region)

K. Azim[1,2] · S. Komenane[2] · B. Soudi[2]

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Abstract
Purpose The region of Souss-Massa generates huge quantities of organic horticultural wastes estimated up to 1,307,465 tons·year^{-1}. Fruit and vegetable producers are asked to process the organic wastes because of the GlobalGAP certification requirements. As a result, there is a need to assess the existing composting plants at regional scale, to improve their efficiency, produce a high-quality soil amendment, free from any pathogens, and weed seeds.
Methods The survey consisted of a diagnosis of the quantitative and qualitative status of the organic horticultural wastes (axillary buds; pruned leaves), and an agro-environmental assessment of nine composting units.
Results The analysis of macronutrients (nitrogen, phosphorus, and potassium) in the organic wastes reveals that 13 million euro worth of N, P, and K can be generated by composting all horticultural wastes (12,000 tons of nitrogen, 6000 tons of phosphorus and 14,000 tons of potassium · year^{-1}), constituting for soils an important source of fertilization backup. Results of field investigations showed that 55% of the composting plants have an area equal to one hectare. The proximity between mature piles and raw materials in 55.5% of cases could highly contaminate them by root knot nematode inoculum. Only 11% of composting units were operating on impermeable surface. The test of circular chromatography showed that 80% of sampled composts are immature, even with high operational costs.
Conclusion Much effort is required to control and optimize the maturation process. The composting activity should be organized through a professional skilled organization, supported by scientific research and government subsidies.

Keywords Tomato by-products · Organic wastes · Composting · Environment · Pollution · Horticulture

Introduction

There is no doubt that sustainable agricultural practices can supply synergies that limit serious effects of the climate change. The report of the FAO stated that sustainable agriculture helps to counteract climate change by restoring soil organic matter content as well as reducing soil erosion and improving soil physical structure (Scialabba and Hattam 2002). Furthermore, global warming increases the rate of soil organic matter mineralization. The evidence for increased carbon sequestration in organic soils seems clear: the addition of manures, compost, mulches, and cover crops restored organic matter (Mae-Wan and Li Ching 2008). Enormous quantities of vegetable wastes are produced annually from the horticultural industries. Composting can be a feasible treatment to stabilize horticultural wastes and, thus, to improve their properties for use as organic fertilizers (Gavilanes et al. 2016). The organic agricultural waste from animal breeding and horticultural production consist mainly of (1) cattle manure and (2) crop residues. The crop residues are considered as plant by-products (Ballerini 2006). In the Souss-Massa region (South Western Morocco), the production of such plant by-

✉ K. Azim
azim.khalid@yahoo.fr

1 Research Unit of Integrated Crop Production, Regional Center of Agronomy Research, INRA-CRRA, B.P.124, CP: 80350 Inzegane, Agadir, Morocco

2 Department of Environment and Natural Resources, IAV Hassan II-Rabat, B.P. 6202, Madinat Al Irfane, Morocco

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product has reached 406,045 tons·year^{-1} (ORMVA/SM 2009). The development of the agricultural production can cause several types of pollution (Elasri and Afilal 2016). Those agricultural wastes, which are not well managed, can lead to serious sanitary and environmental complications, such as soil, air, and groundwater pollution. The good management of those wastes would be an effective means of organic matter restoration through carbon restitution of the depleted soils through organic amendments.

Composting of organic waste products to agricultural land is considered as being one of the most economical, practical, and environmentally beneficial management options (Topal et al. 2016). As a rule, the process consists of the natural biological decomposition of organic waste components and involves diverse species of microorganisms. The final product of such decomposition is a humus-like substance, which can be used successfully either as an agent for soil enrichment or as an organic fertilizer (Neklyudov et al. 2006). In this way, composting could be considered as a feasible treatment for recycling solid organic wastes, since it transforms them into organic amendments and fertilizers that can be used in agricultural soils. However, the application of unstable or immature compost into soils may produce several negative effects, such as phytotoxicity, competition for oxygen between microbial biomass and plant roots/seeds, or plant nitrogen deficiency (Gómez-Brandón et al. 2008). Consequently, compost maturity is the most essential criterion both in recycling organic waste, and in its marketing and utilization in agriculture as organic amendment (Lasaridi et al. 2006). Maturity and stability indicators that have been used in other composting studies include carbon–nitrogen (C/N) ratio, microbial activity, germination index, cation exchange capacity (CEC), humic substances content, compost concentration of water soluble carbon (WSC), dissolved organic matter, NH^{4+}–N and NO^{3-}–N; ratios of NH^{4+}–N = NO^{3-}–N, WSC/TN, and WSC/organic-N (Harada and Inoko 1980; Zucconi et al. 1981; Iglesias-Jiménez and Pérez-García 1992).

To deal with the significant quantities of organic wastes generated locally by greenhouse cropping, farmers in the Souss-Massa region try to use a simple composting technology, such as the dynamic pile (aboveground) method to process animal manure and crop residues. This method is implemented with varying efficiency and has not been fully evaluated. In spite of the increasing interest in this type of organic waste processing, few, if any, papers have been published relating to the composting process evaluation in the Sous Massa region. Besides, there has not been, until now, any regulation that could organize composting activity to prevent a negative impact on the environment. In the light of the situation, the objectives of this study were to (1) evaluate the quantitative and qualitative potentials of crop residues and to (2) compare the performance of composting method used by farmers in terms of both agronomic and economic issues.

Materials and methods

Climate and soil conditions of the studied area

The High-Atlas Mountains in the north and the Anti-Atlas Mountains in the southeast delineate the Souss-Massa plain. Its proximity to the Atlantic Ocean generates a favorable climate for winter production, with mild winters and relatively hot and dry summers. The study was carried out in an irrigated area 30 km to the south of Agadir (latitude = 30.6; longitude = 9.36; altitude = 75 m). The region is characterized by an arid climate with climatic mean values are as follows (Table 1).

Survey method

Data were collected, whilst visiting nine compost plants selected randomly from a total of 13 in the studied region. The nine appointed compost plants were named, respectively, A, B, C, D, E, F, G, H, and I; had been visited (Table 2) and using a questionnaire that was completed by the responsible person in charge.

The questionnaire (Table 3) included questions relating to the origin and the nature of the composted raw materials, mixing ratios, sizing of the plants, and the techniques used for the preservation of natural resources such as soil, water, and air quality with respect to the international standards. At the end of the survey for each composting plant, a qualitative rating was used for indicating environmental impact, process handling, mechanization, and quality of compost. The investigator used four levels of importance: low, medium, high, and very high.

Composting plants description

The configuration of the surveyed plants is more or less variable. They are equipped with storage area for raw wastes and with matured compost area, while the maturing area and the fermentation area are generally confused. These different configurations revealed at the level of the compost plants can cause problems with the quality of the products. Indeed, the very close arrangement between the compost piles and the fermentation piles or even the inorganic refuse pool can lead to mixtures of materials and thus interfere with the normal evolution of the composting process. For instance, composting plant A is configured with a distance of 5 m between the compost pile (which is assumed to be mature) and the inorganic refuse pool. In the composting plant D, it was

Table 1 Souss-Massa plain: climatic mean values (INRA-CRRA Compact Meteo station 2013)

Parameter	Temperature (°C min)	Temperature (°C max)	Humidity (max %)	Humidity (min %)	Insolation (hrs year^{-1})	Rainfall (mm year^{-1})
Values	11.5	24.8	85	55	3600	173

Table 2 Souss-Massa: GPS location of the composting plants

Compost plant	Latitude (°, min, s)	Longitude (°, min, s)
A	30°10′36.9019″N	9°28′07.8298″W
B	30°07′35.8684″N	9°26′58.7508″W
C	30°07′29.9302″N	9°27′12.5878″W
D	30°03′45.0941″N	9°30′44.9514″W
E	30°05′47.1638″N	9°21′57.1954″W
F	30°07′40.8626″N	9°31′02.0095″W
G	30°02′00.0755″N	9°30′17.1227″W
H	30°11′04.3552″N	9°29′57.7241″W
I	30°11′18.4859″N	9°25′43.0473″W

Table 3 Detail of the questionnaire

Nature of the question	Number of questions
Description of the sourcing farms (units that generate organic wastes)	11
Description of the organic wastes generated	14
Composting plant description and sizing	72
Waterproofness	3
Reception, sorting and control area	12
Raw material storage area	10
Fermentation area (thermophile area)	20
Maturation area (curing area)	11
Sifting area	10
Drainage system	6
Operational details	10
Certification (GlobalGAP…)	8
Total of questions	115

noticed that the fermentation piles are almost in the middle of crop wastes and decaying fruits and vegetables. This proximity could lead to the presence of phytopathogens and nematodes inoculum in the final product. Vegetables and especially tomato fruits wastes are disposed for free decaying and not managed at all.

Sampling method

During the survey, samples were taken from the raw wastes intended for the composting, and also at the level of the produced compost. Concerning raw material, different samples were taken from tomato wastes (leaves, axillary buds, and the entire end cycle plant), other vegetables (leaves and stems), citrus (spring pruning buds), banana (post-harvest trunk), and sheep manure. A composite sample of 2 kg of each origin was taken, and three sub-samples of produced compost were taken from at least 70 cm depth at the shaded pile side to constitute a composite sample. All the samples were put in plastic bags, weighed for moisture content after drying at 105 °C 24 h in the oven. Dried samples from raw material and matured compost served for laboratory analysis. Sampling from compost plants C and F were not carried out because of the absence of raw material and matured compost.

Laboratory analysis

Oven dried samples of raw material and compost were sieved ($\varnothing = 2$ mm) and tested for pH in 1:10 soil/water (w/v) suspensions using a glass electrode pH meter (Bio-Block pH meter Microprocessor 99621) at 25 °C (Rhoades 1982). Electrical conductivity (EC) (dS/m) was measured using an electrical conductivity meter (WTW Inolab-Cond Level-2P, Germany, at T°25 °C) in 1:5 soil/water (w/w) solutions. Total Organic Matter content (TOM) was determined by calcination of a dry sample with known moisture content, at 480 °C for 6 h. Total nitrogen content analysis was performed using the standard Kjeldahl procedure (Gerhardt: Kjeldatherm-Vapodest 20, Germany) as described by (Jackson 1967). C/N ratio was calculated by dividing total carbon (issued from TOM) on total nitrogen. Total phosphorus (TP) and total potassium were determined as described by Mehlich (1953). Calcium and magnesium were analyzed by shaking 1 g of compost sample with sodium acetate solution for 1 h prior to atomic absorption spectroscopy detection (Varian Spectra AA 220FS, USA). Qualitative tests of compost samples were performed using the circular chromatography test with silver nitrate as reagent (Brinton 1983).

Results and discussion

Assessment of the organic wastes generated at regional scale

Investigations at farm level compiled with the previous studies (ORMVA/SM 2009; Heck and El Harrak 2010),

Table 4 Estimation of potential macronutrients in the organic wastes produced in Souss-Massa region in 2011

Crops	Quantities of organic wastes produced (T)	Dry Matter content (T)	Percentage of dry organic wastes	Macronutrients content (% w/w of DM)			Estimation of potential macronutrient in the organic waste (T)		
				N	P_2O_5	K_2O	N	P_2O_5	K_2O
Citrus	495,418	435,968	42.41	0.69	1.05	0.95	3008	4578	4142
Other vegetables crops (except tomato wastes)	458,045	290,126	28.22	2.38	0.12	0.5	6905	348	1451
Tomatoes	337,431	297,648	28.95	0.7	0.31	3.01	2084	923	8959
Banana	14,618	2997	0.29	1.17	0.31	1.8	35	9	54
Sheep manure	1953	1325	0.13	1.19	0.31	1.11	16	4	15
Total	1,307,465	1,028,063	100	–	–	–	12,048	5862	14,620

Table 5 Estimation of the economic value of organic agricultural wastes

Macronutrient	Nutrient content of the organic agricultural wastes (tons·year^{-1})	Average price of the corresponding fertilizer (k€/ton)	Economic value of the organic waste (k€)	Percentage (%)
Nitrogen (N)	12,048	0.38	4578.24	33.32
Phosphorus (P)	5862	0.44	2579.28	18.78
Potassium (K)	14,620	0.45	6579.00	47.90
Total Economic Value (k€)			13,736.52	–

Table 4 indicate the quantities of potential macronutrients in the organic wastes. About 25% of the biomass is generated from tomato greenhouses. Tomato wastes represent the major source of interest not only because of the quantities produced, but also due to the high level of water content (71%) which reduces direct processing via on-site composting. Citrus (wood and leaves from autumn and spring pruning) and other vegetable crop residues constitute more than 70%, and are generally not recycled in the soil but presented as fodder for cattle, or in case of abundance, not composted but thrown outside the farms. Workers for cooking and heating purposes generally take woody residues from citrus plantations. Cow manure production represents only 0.13% of the organic wastes; this can be explained by its direct soil amendment by farmers in their citrus orchards, since most of them have dairy production. Hence, actual quantities of produced cow manure are not recorded. On the other hand, farmers use sheep manure in organic fertilization rather than cow manure because of its low price and its availability from other regions.

In terms of macronutrients, potential nitrogen from other vegetables crop wastes seems to be important. About 6900 tons of nitrogen that represents 57.2% of the total potential nitrogen can be valorized from vegetables crop residues (except tomato residues) by composting. Similarly, potential potassium from tomato wastes is estimated up to 9000 tons and represents about 61% of the total potential potassium source in the region.

According to the analysis of the macro-element (nitrogen, phosphorus and potassium) of the organic waste samples (Table 5), 13 million euro worth of N, P, and K can be generated through composting of organic residues from different horticultural crops. Farmers commonly take into consideration the fertilizer uptake of the crops during the cropping cycle when setting fertilization program. Unfortunately, they do not consider the representation of macronutrients concealed in the organic waste generated during the cultivation cycle. Potential potassium worth is highly significant and represents about 48% due to its high content particularly in tomato residues.

Composting plant description and sizing

Description

Collected data of this first part are given in Table 6, and represent the description and the positioning of the compost plants within their environments.

The assessment showed that 67% of the composting plants have an area equal or higher that 1 ha (average of 1.24 ha), and are completely separated from the production farm, reflecting the awareness of the producers of contamination risks due to inappropriate composting technics.

Size

The size of the composting units did not respect the logical workflow of the composting process, mainly due to

Table 6 Description of the composting plants environment

Compost plant	Total area of the farm (ha)	Compost plant surface	Distance from the well (m)	Distance from the habitation	Soil type
A	1	1 ha	5	≈10 m	Sandy loam
B	1	1 ha	>500	≈50 m	Sandy loam
C	6	2000 m^2	>500	>500 m	Sandy loam
D	4	150 m^2	>500	>500 m	Sandy loam
E	220	1 ha	>500	>500 m	Sandy
F	1	1 ha	≈500	≈25 m	Sandy loam
G	1	1 ha	>500	>500 m	Sandy loam
H	22	700 m^2	≈5	≈25 m	Sandy loam
I	45	600 m^2	0	≈1.5 km	Sandy loam

confusion between fermentation and maturing phase. The proximity between the raw material and maturation piles in 55.5% of cases could result in a high degree of contamination by phytopathogens and nematode inoculum. In addition, only 11% of the surveyed units had impermeable surface and drainage facilities to collect compost leachates. Two management approaches have been identified:

- *High-quality compost production* 56% of composting plants are mixing sheep manure and olive mill wastes to produce compost;
- *Organic waste management* 44% of composting plants convert tomato waste into an acceptable organic amendment. The produced compost is used as an amendment to soil of citrus orchard to avoid potential inoculation with root knot nematodes that could not be suppressed by composting due to the low level of sanitization.

Operational details as illustrated in Table 7, data set reveals that only 37.5% of compost plants are treating tomato wastes, whilst the rest are composting manure and olive mill wastes. The lack of scientific and technical data of tomato wastes composting could be the origin of this result. Based on survey responses, mixing ratios in all the compost plants are based on empirical experience instead of scientifically based recommendations. Composting plants that manage tomato wastes do not use any additional raw material to decrease the C/N ratio to 30 as recommended by literature. Tomato wastes, in general, consist of the whole plant (main stem, leaves, and some small immature fruits) and have a C/N ratio about 47 making the composting process too long (7 months). Roots are not composted, but incinerated to avoid root knot nematode contamination to amended soils.

Agronomic performance of the material and the final compost

Table 8 reveals that C/N ratios of different final composts are above the optimal value of 12–15, and it is mostly due to the mixing ratio of different raw materials that result in the initial C/N ratio above the optimal value of 30. As a result, 40% of final composts are not mature and still need to be processed for an extra maturation phase. Total nitrogen of final compost OMW + SM and SM are better when compared to the compost of TW. This is due mainly to the fact that composting TW only is not optimal with regard to its high C/N ratio and low moisture content. Concerning the agronomic value, nutrient content of all final compost complies with the recommendations of the Bulletin of Transfer of Technology in Agriculture (Soudi 2005).

With regard to the nutrient content from the final compost samples, results showed that for 100 g of compost, average of nutrients content can be estimated as follows: nitrogen = 0.82 g; phosphorus = 0.5 g; potassium = 0.958 g. The Total Organic Carbon (TOC) is high in all composts and exceeds the threshold given by the World Health Organization (WHO). The high levels of the TOC are due to the initial TOC of the raw material, as well as there was no additional raw material added with high TN to decrease the C/N ratio of the mixture. High levels of TOC will need more time (3 months) to be decomposed, thus increasing operational costs of the produced compost. Regarding the other standards, the produced compost complies with the acceptance thresholds. The composts have a moisture content ranging from 30 to 50% and a rather alkaline pH ranging from 8.4 to 9.8. Electrical Conductivity (EC) measurements show values ranging from 2.6 to 4.8 dS/m. These values are in conformity with threshold given by Francou (2003).

Qualitative test of final compost

This test of maturity (reagent silver nitrate) was used to assess the maturity of various composts. Among five tested composts, only 20% presented an advanced degree of maturity whereas 80% were immature. It is likely that immature compost could spread phytopathogens and

Table 7 Operational details of the surveyed composting plants

Compost unit	Parameters										
	Process duration (months)	Quantity of treated wastes (T year^{-1})	Nature of waste	Origin of wastes	Cost (wastes + transportation) €/T	Mixing ratio	Fermentation area (S)	Fermentation phase (months)	Maturing phase (months)	Height of pile (m)	Width of pile (m)
A	4	7000	Sheep manure	Local market	41	50%	2500 m^2	2	2	1.5	2
			Olive mill wastes	Marrakech region	18	50%					
B	6	2160	Tomato waste	On farm (54 ha)	0	100%	–	2	4	2	2
C	3	–	Sheep manure	Beni Mellal region	45	33%	100 m^2	2	1	2	5
			Cow manure			33%					
			Olive mill wastes	Marrakech region	18	33%					
D	4–7	20,880	Tomato waste	On farm (240 ha)	0	100%	300 m^2	4	Variable	3	3
E	3	2400	Sheep manure	Local market	13	100%	0.5 ha	2	1	2.5	2
F	5–7	4698	Tomato waste	On farm (70 ha)	0	28% leaves	0.5 ha	4	Variable	4	4
						70% stems					
						2% fruits					
H	5	744	Cow manure	Local market	40	85%	210 m^2	1	4	1.6	3
			Olive mill wastes	Marrakech region	23	15%					
I	5	276	Sheep manure	Local market	40	66%	400 m^2	1	4	1.5 m	2.5 m
			Olive mill wastes	Marrakech region	33	33%					

Table 8 Physical and chemical analyses of raw material and final compost

Parameters	Input material						Compost						WHO standards (1993) Min–Max
	OMW + SM		SM		TW		OMW		TW		SM		
	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	–
Moisture	36%	17%	26%	16%	40%	18%	37%	6%	47%	3%	37%	4%	–
pH	9.40	0.28	7.69	1.05	8.14	0.48	9.40	0.582	8.93	0.06	8.63	0.20	6–9
EC (dS/m)	5.86	0.08	2.98	2.51	2.85	1.17	3.77	0.287	2.92	0.32	4.32	0.56	2–5
TOC	67.01	1.41	71.63	23.30	77.55	9.11	63.25	5.596	60.25	1.32	56.47	2.74	30–40
TMM	32.99	1.41	28.37	23.30	22.45	9.11	36.75	5.596	39.75	1.32	43.53	2.74	–
C/N Ratio	39.79	9.60	50.24	11.65	29.92	7.18	23.92	0.767	22.94	0.44	32.41	3.33	20–30
TN	0.87	0.19	0.78	0.41	1.36	0.37	1.33	0.145	1.31	0.03	0.88	0.08	0.10–1.80
P_2O_5	2.50	1.84	2.00	0.10	1.21	1.35	1.62	0.801	0.73	0.05	1.61	1.09	0.10–2.30
K_2O	1.74	0.25	0.99	0.56	1.19	0.12	1.58	0.454	1.57	0.08	0.98	0.76	0.10–1.70
Na_2O	0.44	0.41	0.27	0.26	0.24	0.20	0.29	0.259	0.16	0.01	0.09	0.05	–
CaO	6.78	1.66	4.58	3.12	3.77	1.35	5.30	2.403	7.67	0.67	5.35	3.27	–
MgO	0.79	0.32	0.42	0.14	0.51	0.14	0.81	0.378	0.74	0.03	0.38	10	–

OMW Olive Mill Waste, *SM* Sheep Manure, *TW* Tomato Waste, *SD* Standard Deviation, *WHO* World Health Organization

Table 9 Summary of the assessment criteria of the composting plants in the Souss-Massa

Compost plants	Environmental impact	Process handling	Mechanization	Quality of compost
A	Very high	High	Low	Medium
D	Very high	High	High	Low
E	Medium	Very high	Medium	Medium
F	Very high	High	Very high	Low
G	High	High	Very high	High
H	Low	High	Very low	Medium
I	Low	High	Very low	Medium

nematodes, especially root knot nematodes that could result in up to 90% of tomato yield loss. Furthermore, the amendment of immature compost could cause asphyxia of roots because of the high level of oxygen consumption by soil microorganisms as stated by Smith and Hughes (2004). As a soil amendment, immature compost will continue to be degraded by microorganisms that consume more oxygen and consequently cause damage to the plant at rhizosphaera level.

Assessment criteria of the composting plants in Souss-Massa

The process of composting presents a positive effect on the environment, especially for the effective management of produced waste. However, there are some failures in the management of mechanization, especially in relation to the quality of the final product. Table 9 shows the assessment summary of the studied composting plants.

Environmental impacts are high because of the absence of the impermeability of the composting plant. Leachates (especially during the rainy season) can infiltrate the sandy soil and be considered as a potential pollutant of the ground water. Concerning the process handling, management of the residues is very organized to the extent of enabling a rapid workflow, consequently processing the maximum residues per year. Regarding the mechanization, there is a heterogeneity in the perception. The composting plants that turn tomato and citrus residues are more mechanized than the others that compost sheep and olive mill wastes. This can be explained by the fact that tomato and citrus residues are more important in volumes and hence need more mechanization. Quality of the compost is the most important criterion for this assessment, but could be at odds with the qualitative test mentioned above. The quality of compost in this assessment refers to the physical and chemical parameters (agronomic parameters), whilst the maturity test refers to the degree of humification of the organic matter. High levels of TOC require a long maturation phase to allow proper humification.

Conclusion

This diagnosis concludes that there is a potential of organic wastes estimated up to 1 Million of dry matter year^{-1}, and 13 million euro worth of N, P, and K can be generated by composting all horticultural wastes. Compost has not only beneficial effects on soil fertility, but also on plant nutrition. However, the lack of regulation relating to the composting activity in Morocco engenders problems of process monitoring and low quality of produced compost. This maturity not being achieved can present serious phytotoxic risks for the crops. The functioning of the composting plants raises problems of water pollution, whilst the effects on the soil need to be studied further. The management policies of wastes should favor its valorization, either in terms of recycling, or in terms of energy valuation. Composting activity should be organized through a professional association, and employs a skilled labor force to ensure impermeable composting plants. The use of computer software for the optimization of mixtures should also be encouraged. Furthermore, the optimal composting approach is the open dynamic windrow, using necessarily a compost turner to homogenize the organic material. There is no need to remind that the monitoring of temperature and oxygen uptake and carbon dioxide release are important to achieve an adequate maturity level. For this purpose, also there are many multi-parametric devices available for large composting plant. The acceptance by local farmers of the benefits of compost to the soil and crops would be a significant incentive to reduce the expensive mineral fertilizers and optimize their use. The development of the composting activities is actually limited and has to be supported by scientific research to afford a better knowledge concerning the real impact of compost on agriculture, environment, and public health.

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